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(71) Applicant (*for all designated States except US*): NIKON RESEARCH CORPORATION OF AMERICA [US/US]; 1399 Shoreway Road, Belmont, CA 94002-4107 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **POON, Alex Ka Tim** [US/US]; 158 Elisha Lane, San Ramon, CA 94583 (US). **KHO, Leonard Wai Fung** [—/US]; 1425 Fillmore Street, Apartment 313, San Francisco, CA 94115 (US).

(74) Agents: LEUNG, Chun-Pok et al.; Townsend and Townsend and Crew LLP, Two Embarcadero Center, 8th Floor, San Francisco, CA 94111-3834 (US).

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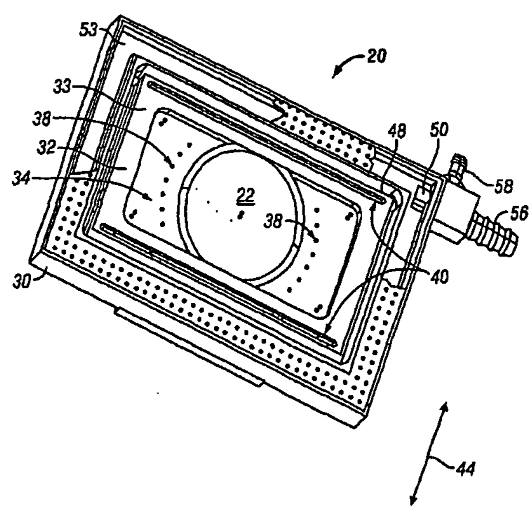
(54) Title: APPARATUS AND METHOD FOR PROVIDING FLUID FOR IMMERSION LITHOGRAPHY



(57) Abstract: Embodiments of the present invention are directed to a system and a method of controlling the fluid flow and pressure to provide stable conditions for immersion lithography. A fluid is provided in a space between the lens and the substrate during the immersion lithography process. Fluid is supplied to the space and is recovered from the space through a porous member in fluidic communication with the space. Maintaining the pressure in the porous member under the bubble point of the porous member can eliminate noise created by mixing air with the fluid during fluid recovery. In one embodiment, the method comprises drawing the fluid from the space via a recovery flow line through a porous member; and maintaining a pressure of the fluid in the porous member below a bubble point of the porous member during drawing of the fluid from the space.

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APPARATUS AND METHOD FOR PROVIDING FLUID FOR IMMERSION LITHOGRAPHY

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application is based on and claims the benefit of U.S. Provisional Patent Application No. 60/500,312, filed September 3, 2003,and U.S. Provisional Patent Application No. 60/541,329, filed February 2, 2004, the entire disclosures of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to a system and a method for providing fluid for immersion lithography and, more particularly, for controlling the fluid flow and pressure to provide stable conditions for immersion lithography.

[0003] An exposure apparatus is one type of precision assembly that is commonly used to transfer images from a reticle onto a semiconductor wafer during semiconductor processing. A typical exposure apparatus includes an illumination source, a reticle stage assembly that retains a reticle, an optical assembly, a wafer stage assembly that retains a semiconductor wafer, a measurement system, and a control system. The resist coated wafer is placed in the path of the radiation emanating from a patterned mask and exposed by the radiation. When the resist is developed, the mask pattern is transferred onto the wafer. In microscopy, extreme ultra violet (EUV) radiation is transmitted through a thin specimen to a resist covered plate. When the resist is developed, a topographic shape relating to the specimen structure is left.

[0004] Immersion lithography is a technique which can enhance the resolution of projection lithography by permitting exposures with numerical aperture (NA) greater than one, which is the theoretical maximum for conventional "dry" systems. By filling the space between the final optical element and the resist-coated target (i.e., wafer), immersion lithography permits exposure with light that would otherwise be totally internally reflected at an optic-air interface. Numerical apertures as high as the index of the immersion liquid (or of the resist or lens material, whichever is least) are possible. Liquid immersion also increases the wafer depth of focus, i.e., the tolerable error in the vertical position of the wafer, by the

index of the immersion liquid compared to a dry system with the same numerical aperture. Immersion lithography thus has the potential to provide resolution enhancement equivalent to the shift from 248 to 193 nm. Unlike a shift in the exposure wavelength, however, the adoption of immersion would not require the development of new light sources, optical materials, or coatings, and should allow the use of the same or similar resists as conventional lithography at the same wavelength. In an immersion system where only the final optical element and its housing and the wafer (and perhaps the stage as well) are in contact with the immersion fluid, much of the technology and design developed for conventional tools in areas such as contamination control, carry over directly to immersion lithography.

[0005] One of the challenges of immersion lithography is to design a system for delivery and recovery of a fluid, such as water, between the final optical element and the wafer, so as to provide a stable condition for immersion lithography.

BRIEF SUMMARY OF THE INVENTION

[0006] Embodiments of the present invention are directed to a system and a method of controlling the fluid flow and pressure to provide stable conditions for immersion lithography. A fluid is provided in a space between the lens and the substrate during the immersion lithography process. Fluid is supplied to the space and is recovered from the space through a porous member in fluidic communication with the space. Maintaining the pressure in the porous member under the bubble point of the porous member can eliminate noise created by mixing air with the fluid during fluid recovery. The bubble point is a characteristic of the porous member which depends on the size of the holes in the porous member (the largest hole) and the contact angle which the fluid forms with the porous member (as a parameter based on the property of the porous material and the property of the fluid). Because the bubble point is typically a very low pressure, the control of this low pressure becomes an important issue.

[0007] An aspect of the present invention is directed to a method of recovering a fluid from a space between a lens and a substrate in an immersion lithography system. The method comprises drawing the fluid from the space via a recovery flow line through a porous member; and maintaining a pressure of the fluid in the porous member below a bubble point of the porous member during drawing of the fluid from the space.

[0008] In some embodiments, maintaining the pressure comprises providing an overflow container kept at a preset pressure; and directing the fluid drawn from the space through the porous member via the recovery flow line to the overflow container. Maintaining the pressure further comprises siphoning the fluid from the overflow container to a collection tank. The fluid is siphoned downed by gravity to the collection tank disposed below the overflow container. In other embodiments, maintaining the pressure comprises providing a fluid level buffer; drawing the fluid from the space via a buffer flow line through the porous member to the fluid level buffer; sensing a pressure or a fluid level at the fluid level buffer; and controlling the fluid flow drawn from the space via the recovery flow line through the porous member based on the sensed pressure or fluid level at the fluid level buffer. Controlling the fluid flow comprises controlling a variable valve disposed in the recovery flow line downstream of the porous member. In still other embodiments, maintaining the pressure comprises providing a fluid level buffer; drawing the fluid from the space via a buffer flow line through the porous member to the fluid level buffer; sensing a pressure or a fluid level at the fluid level buffer; and controlling a vacuum pressure at an outlet of the recovery flow line through the porous member based on the sensed pressure or fluid level at the fluid level buffer. Controlling the vacuum pressure comprises controlling a vacuum regulator in a collection tank at the outlet of the recovery flow line.

[0009] In accordance with another aspect of the invention, an apparatus for recovering a fluid from a space between a lens and a substrate in an immersion lithography system comprises an inner part including a lens opening to accommodate a portion of the lens and position the lens apart from the substrate separated by the space to receive a fluid in the space between the lens and the substrate. An outer part is disposed around the inner part, and includes a porous member fluidicly coupled with the space and with a fluid recovery outlet to draw fluid from the space via the porous member to the fluid recovery outlet. A pressure control system is fluidicly coupled with the porous member to maintain a pressure at the surface of the porous member below a bubble point of the porous member during drawing of the fluid from the space via the porous member.

[0010] In some embodiments, the pressure control system comprises an overflow container fluidicly coupled with the porous member; and a vacuum regulator configured to regulate a pressure in the overflow container. A collection tank is fluidicly coupled to and disposed below the overflow container. In other embodiments, the pressure control system comprises a fluid level buffer fluidicly coupled with the porous member; a sensor configured to sense a

pressure or a fluid level at the fluid level buffer; and a controller configured to adjust a flow rate of the fluid drawn from the space through the fluid recovery outlet, based on a sensor signal from the sensor, to maintain a pressure at the surface of the porous member below a bubble point of the porous member during drawing of the fluid from the space via the porous member. The pressure control system comprises a valve disposed downstream of the fluid recovery outlet, and the controller is configured to control the valve to adjust the flow rate of the fluid drawn from the space through the fluid recovery outlet. In still other embodiments, the pressure control system comprises a collection tank fluidicly coupled to the fluid recovery outlet; and a controllable vacuum regulator configured to regulate a pressure in the collection tank. The controller is configured to control the controllable vacuum regulator to adjust the flow rate of the fluid drawn from the space through the fluid recovery outlet to the collection tank by controlling the pressure in the collection tank.

[0011] In specific embodiments, the inner part is spaced from the outer part by an intermediate spacing. The inner part includes an inner cavity forming a part of the spacing between the lens and the substrate, and the inner part includes apertures disposed above the inner cavity for at least one of introducing fluid into and drawing fluid from the inner cavity. The inner part includes apertures disposed on opposite sides of the lens opening for introducing fluid into the inner cavity. The inner part includes a pair of buffer slots disposed on opposite sides of the lens opening in a direction of scan of the immersion lithography system. The inner part includes purge holes and wherein each of the pair of buffer slots is fluidicly coupled to at least one of the purge holes. The porous member is selected from the group consisting of a mesh, a porous material, and a member having etched holes therein.

[0012] In accordance with another aspect of the invention, an apparatus comprises an optical projection system having a last optical element and configured to project an image onto a workpiece; and a stage configured to support the workpiece adjacent the optical projection system when the image is being projected onto the workpiece. A gap is provided between the last optical element and the workpiece, and is configured to be filled with an immersion fluid. A porous material is positioned adjacent the gap, and is configured to recover fluid exiting the gap. A control system is configured to maintain a pressure on the porous material. The pressure is at or below the bubble point of the porous material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Fig. 1 is a simplified elevational view schematically illustrating an immersion lithography system according to an embodiment of the present invention.

[0014] Fig. 2 is a perspective view of a nozzle for fluid delivery and recovery for immersion lithography according to one embodiment of the present invention.

[0015] Fig. 3 is a simplified cross-sectional view of the nozzle of Fig. 2.

[0016] Fig. 4 is a cross-sectional view of the inner part of the nozzle of Fig. 2.

[0017] Fig. 5 is a simplified cross-sectional view of the nozzle according to another embodiment.

[0018] Fig. 6 is simplified view schematically illustrating a pressure control system for fluid recovery in an immersion lithography system according to one embodiment of the present invention.

[0019] Fig. 7 is simplified view schematically illustrating a pressure control system for fluid recovery in an immersion lithography system according to another embodiment of the present invention.

[0020] Fig. 8 is simplified view schematically illustrating a pressure control system for fluid recovery in an immersion lithography system according to another embodiment of the present invention.

[0021] Fig. 9 is a simplified view schematically illustrating a pressure control system for fluid recovery in an immersion lithography system with water stagnation prevention according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0022] Fig. 1 show an immersion lithography system 10 including a reticle stage 12 on which a reticle is supported, a projection lens 14, and a wafer 16 supported on a wafer stage 18. An immersion apparatus 20, which is sometimes referred to herein as a showerhead or a nozzle, is disposed around the final optical element 22 of the projection lens 14 to provide and recover a fluid, which may be a liquid such as water or a gas, between the final optical element 22 and the wafer 16. In the present embodiment, the immersion lithography system

10 in which the reticle and the wafer 16 are moved synchronously in respective scanning directions during a scanning exposure.

[0023] Figs. 2 and 3 show the apparatus or nozzle 20 for delivery and recovery of the fluid between the final optical element 22 and the wafer 16 for immersion lithography. Fig. 2 shows the bottom perspective view of the nozzle 20, which includes an outer part 30 and an inner part 32. The inner part 32 defines an inner cavity 34 to receive the fluid between the final optical element 22 and the wafer 16. The inner part 32 includes apertures 38 for fluid flow into and out of the inner cavity 34. As seen in Fig. 2, there are apertures 38 disposed on both sides of the final optical element 22. The inner part 32 has a flat portion 33 surrounding the inner cavity 34. The flat portion 33 is substantially parallel to the wafer 16. The distance D1 between the end surface of the final optical element 22 and the wafer 16 is greater than the distance D2 between the flat portion 33 and the wafer 16. The distance D1 could be 1.0-5.0 mm, and the distance D2 could be 0.5-2.0 mm. In another embodiment, the distance D1 is substantially equal to the distance D2. The inner part 32 further includes a pair of buffers or buffer slots 40 with purge holes 42. The buffers 40 are arranged at or near the flat portion 33. The buffers 40 are disposed on opposite sides of the final optical element 22. A cross-sectional view of the inner part 32 in the direction of scan 44 is illustrated in Fig. 4.

[0024] The outer part 30 is spaced from the inner part 32 by an intermediate spacing or groove 48, which may be referred to as an atmospheric groove. The outer part 30 includes one or more fluid recovery openings 50 disposed on opposite sides of the final optical element 22. A porous member 51 is disposed in a slot or outer cavity 53 which extends around the inner part 32 and fluidicly communicates with the pair of fluid recovery openings 50. The porous member 51 may be a mesh or may be formed of a porous material having holes typically in the size range of about 50-200 microns. For example, the porous member 51 may be a wire mesh including woven pieces or layers of material made of metal, plastic, or the like, a porous metal, a porous glass, a porous plastic, a porous ceramic, or a sheet of material having chemically etched holes (e.g., by photo-etching). The outer part 30 further includes a fluid buffer outlet 56 and a fluid recovery outlet 58. In another embodiment of the nozzle 20' as seen in Fig. 5, the inner part 32 does not contact or form a seal with the final optical element 22, but is spaced from the final optical element 22. The gap prevents nozzle vibrations from being transmitted to the final optical element 22. However, the gap may allow the fluid to be exposed to air.

[0025] One feature of the nozzle 20 is that it is made in two pieces, namely, the outer part 30 and the inner part 32. The inner part 32 keeps the fluid between the lens and the wafer surface, and the outer part 30 is mainly provided for fluid recovery. Vibration might be introduced during fluid recovery from the outer part 30 through the porous member 51 to the other components of the lithography system, including the inner part 32 which may be used to direct an autofocus beam to the wafer 16. A damping material can be mounted between the outer part 30 and the mounting piece to which the outer part 30 is mounted to minimize the transmission of vibration from the outer part 30. In addition, the outer part 30 that includes the porous member may be prone to contamination and thus needs to be replaced for maintenance. Making the outer part 30 as a separate part facilitates easier maintenance. It can also minimize readjustment and recalibration time after replacement of the outer part as opposed to replacing the entire nozzle 20. Manufacturability of the nozzle 20 can also be improved if the nozzle 20 is made in two separate parts. It is understood that the nozzle 20 may be made of a single piece in alternative embodiments.

[0026] Another feature of the nozzle 20 is the atmospheric groove 48 between the inner part 32 and the outer part 30. This atmospheric groove 48 functions as a breaking edge to prevent fluid in the inner part 30 from being drawn out by the porous member 51 on the outer part 30 if the fluid recovery rate is faster than the fluid supply rate. In the situation when there is no breaking edge, a balance between the fluid recovery rate and the fluid supply rate has to be maintained so that fluid can be kept within the inner part 32 at all times during scanning. Having the atmospheric groove 48 allows the recovery rate to be set at a maximum to minimize fluid leakage out of the outer part 30 during scanning. The atmospheric groove 48 also acts as a buffer for fluid to go in and out during scanning, minimizing water supply and recovery requirements.

[0027] In the process of immersion lithography, a fluid is to be filled between the projection lens 14 and the wafer 16 from a dry state and, at other times, the fluid is to be recovered. For example, in the beginning of exposure of a new wafer, the fluid is to completely fill the inner cavity 34 of the inner part 32 before starting exposure. During this process, ideally no air bubbles can exist between the projection lens 14 and wafer 16 or other optical paths such as the auto focus beam. The fluid supply in the inner cavity of the inner part 32 is designed to be at the highest point in the cavity (via apertures 38) so that the fluid is filled from top down, allowing air bubbles to be pushed out of the inner cavity during the filling process. The fluid desirably is initially supplied from one side in this embodiment (the

set of apertures 38 on one side), so that the fluid is filled from one side to the other, again allowing air bubbles to be pushed out to avoid trapping air therein. Other arrangements are also possible, as long as the fluid is being filled from the inside out.

[0028] On occasion, the fluid has to be fully recovered from the inner cavity of the inner part 32. In Fig.1, there are small holes 42 in each of the buffers 40 in the inner cavity. These holes 42 are provided for fast fluid recovery or fluid purge when the fluid has to be fully recovered. Sucking the fluid out from these holes 42 using high vacuum with the combination of some movement in the wafer stage 18 allows all the fluid to be recovered within a reasonable time.

[0029] The inner part 32 has two groups or rows of holes 38 for supplying or recovering the fluid. Each row can be independently controlled to either supply or recover the fluid. In the case where both rows are chosen for fluid supply, all the fluid is recovered through the porous member 51 in the outer part 30. Since both rows are supplying fluid, a pressure can build up in the inner cavity causing deformation of the final optical element 22 of the projection lens 14 or the wafer 16 or both. The fluid flow across the final optical element 22 may also be limited, and thus the temperature of the fluid between the final optical element 22 and the wafer 16 may eventually rise, causing adverse effect. On the other hand, if one row is chosen for supply and the other for recovery, a fluid flow will be driven across the final optical element 22, minimizing temperature rise. It can also reduce the pressure otherwise created by supplying fluid from both rows. In this case, less fluid needs to be recovered through the porous member 51, lowering the fluid recovery requirement in the porous member. In other nozzle configurations, multiple fluid supplies and recoveries may be provided so as to optimize the performance.

[0030] During scanning motion of the wafer stage 18 (in the direction of scan 44 in Fig. 2), the fluid may be dragged in and out of the inner cavity of the inner part 32. When the fluid is dragged out, it is recovered through the porous member 51 in the outer part 30. When the wafer stage 18 is moved in the opposite direction, air may be dragged into the inner cavity of the inner part 32. During this time, the fluid in the buffers 40, as well as the fluid supplied from within the inner cavity, helps to refill the fluid that is dragged along the scanning direction, preventing air from getting into the inner cavity. The buffers 40 and the porous member 51 work together to minimize fluid leaking out from the outer part 30, and air

dragging into the inner cavity of the inner part 32 during scanning motion of the wafer stage 18.

[0031] Recovering fluid through the porous member 51 by maintaining the pressure in the porous member 51 under the bubble point can eliminate noise created by mixing air with the fluid during fluid recovery. The bubble point is a characteristic of the porous member 51 which depends on the size of the holes in the porous member 51 (the largest hole) and the contact angle which the fluid forms with the porous member 51 (as a parameter based on the property of the porous material and the property of the fluid). Due to the fact that the bubble point is typically a very low pressure (e.g., about 1000 pascal), the control of this low pressure becomes an important issue. Figs. 6-7 illustrate three specific ways of maintaining the pressure below the bubble point during fluid recovery.

[0032] In the pressure control system 100 of Fig. 6, a pressure under bubble point is maintained at the surface of the porous member 51 using a vacuum regulator 102 with the assistance of an overflow container or tank 104 fluidicly coupled to the porous member 51 by a recovery flow line 106 (which is connected to the fluid buffer outlet 56). The pressure at the surface of the porous member 51 is equal to the pressure maintained by the vacuum regulator 102 subtracting the pressure created by the height of the fluid above the porous member 51. By maintaining a constant height of fluid above the porous member 51 using the overflow tank 104 allows easy control of the pressure at the surface of the porous member 51. The fluid that is recovered through the porous member 51 will overflow and be siphoned down along a siphon line 108 to a collection tank 110, which is disposed below the overflow tank 104. An optional flow path 112 is connected between the overflow tank 104 and the collection tank 110 to assist in equalizing the pressure between the overflow tank 104 and the collection tank 110 and facilitate flow along the siphon line 108. One feature of this pressure control system 100 is that it is a passive system without the necessity of control.

[0033] In the pressure control system 120 of Fig. 7, the pressure at the surface of the porous member 51 is maintained below the bubble point using a vacuum regulator 122 at a water level buffer 124 which is fluidicly coupled with the porous member 51 by a buffer flow line 126 (which is connected to the fluid buffer outlet 56). A pressure transducer or a water level sensor 128 is used to measure the pressure or fluid level at the fluid level buffer 124. The sensor signal is then used for feedback control 130 to a valve 132 that is disposed in a recovery flow line 134 (which is connected to the fluid recovery outlet 58) connected

between the porous member 51 and a collection tank 136. The valve 132 may be any suitable valve, such as a proportional or variable valve. The variable valve 132 is adjusted to control the fluid flow through the fluid recovery line 134 to the collection tank 136 to maintain the pressure or fluid level of the fluid level buffer 124 at a preset value. The collection tank 136 is under a relatively higher vacuum controlled by a high vacuum regulator 138 for fluid recovery. In this fluid control system 120, no overflow tank is needed and the collection tank 136 can be placed anywhere in the system and need not be disposed below an overflow tank. An on/off valve 140 is desirably provided in the fluid recovery line 134 and is switched off when fluid recovery is not required.

[0034] In Fig. 8, the pressure control system 160 is similar to the system 120 of Fig.7, and like reference characters are used for like parts. Instead of using the valve 132 for the feedback control of fluid recovery, this system 160 employs a controllable vacuum regulator 162 for the feedback control of fluid recovery. The vacuum regulator 162 is typically electronically controllable to adjust the vacuum pressure in the collection tank 136 based on the sensor signal from the pressure transducer or a water level sensor 128. The vacuum regulator 162 is adjusted to control the fluid flow through the fluid recovery line 134 to the collection tank 136 to maintain the pressure or fluid level of the fluid level buffer 124 at a preset value. The on/off valve 140 in the fluid recovery line 134 is switched off when fluid recovery is not required.

[0035] Fig. 9 shows a pressure control system for fluid recovery in an immersion lithography system with water stagnation prevention according to another embodiment of the present invention. The pressure control system 180 is similar to the system 120 of Fig. 7 having the same components with the same reference characters. In addition, the water level buffer 124 is fluidicly coupled with a water supply or water recovery 182 to supply water to or recover water from the water level buffer 124 to prevent stagnation. An optional pump or a similar moving part may be used to induce flow between the water level buffer 124 and the water supply or water recovery 182. There is a possibility of bacteria/fungus growth in stagnated water or fluid over time. Under normal operation, the water at the water level buffer 124 is stagnated because water recovered from the mesh 51 will go through the small tube at the mesh level to the collection tank 136. By inducing flow into or out of the water level buffer 124 during normal operation, the bacteria/fungus growth problem can be prevented.

[0036] It is to be understood that the above description is intended to be illustrative and not restrictive. Many embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.

[0037] Also, the present invention could be applied to Twin-Stage-Type Lithography System. Twin-Stage-Type Lithography System, for example, is disclosed in U.S. Patent No. 6,262,796 and U.S. Patent No. 6,341,007, the entire disclosures of which are incorporated herein by reference.

WHAT IS CLAIMED IS:

1. A method of recovering a fluid from a space between a lens and a substrate in an immersion lithography system, the method comprising:

drawing the fluid from the space via a recovery flow line through a porous member; and

maintaining a pressure of the fluid in the porous member below a bubble point of the porous member during drawing of the fluid from the space.

2. The method of claim 1 wherein maintaining the pressure comprises:

providing an overflow container kept at a preset pressure; and

directing the fluid drawn from the space through the porous member via the recovery flow line to the overflow container.

3. The method of claim 2 wherein maintaining the pressure further comprises siphoning the fluid from the overflow container to a collection tank.

4. The method of claim 3 wherein the fluid is siphoned downed by gravity to the collection tank disposed below the overflow container.

5. The method of claim 1 wherein maintaining the pressure comprises:

providing a fluid level buffer;

drawing the fluid from the space via a buffer flow line through the porous member to the fluid level buffer;

sensing a pressure or a fluid level at the fluid level buffer; and

controlling the fluid flow drawn from the space via the recovery flow line through the porous member based on the sensed pressure or fluid level at the fluid level buffer.

6. The method of claim 5 wherein controlling the fluid flow comprises controlling a variable valve disposed in the recovery flow line downstream of the porous member.

7. The method of claim 1 wherein maintaining the pressure comprises:

providing a fluid level buffer;

drawing the fluid from the space via a buffer flow line through the porous member to the fluid level buffer;

sensing a pressure or a fluid level at the fluid level buffer; and

controlling a vacuum pressure at an outlet of the recovery flow line through the porous member based on the sensed pressure or fluid level at the fluid level buffer.

8. The method of claim 7 wherein controlling the vacuum pressure comprises controlling a vacuum regulator in a collection tank at the outlet of the recovery flow line.

9. An apparatus for recovering a fluid from a space between a lens and a substrate in an immersion lithography system, the apparatus comprising:

an inner part including a lens opening to accommodate a portion of the lens and position the lens apart from the substrate separated by the space to receive a fluid in the space between the lens and the substrate;

an outer part disposed around the inner part, the outer part including a porous member fluidicly coupled with the space and with a fluid recovery outlet to draw fluid from the space via the porous member to the fluid recovery outlet; and

a pressure control system fluidicly coupled with the porous member to maintain a pressure at the surface of the porous member below a bubble point of the porous member during drawing of the fluid from the space via the porous member.

10. The apparatus of claim 9 wherein the pressure control system comprises:

an overflow container fluidicly coupled with the porous member; and

a vacuum regulator configured to regulate a pressure in the overflow container.

11. The apparatus of claim 10 further comprising a collection tank fluidicly coupled to and disposed below the overflow container.

12. The apparatus of claim 9 wherein the pressure control system comprises:

a fluid level buffer fluidicly coupled with the porous member;

a sensor configured to sense a pressure or a fluid level at the fluid level buffer; and

a controller configured to adjust a flow rate of the fluid drawn from the space through the fluid recovery outlet, based on a sensor signal from the sensor, to maintain a pressure at the surface of the porous member below a bubble point of the porous member during drawing of the fluid from the space via the porous member.

13. The apparatus of claim 12 wherein the pressure control system comprises a valve disposed downstream of the fluid recovery outlet, and wherein the controller is configured to control the valve to adjust the flow rate of the fluid drawn from the space through the fluid recovery outlet.

14. The apparatus of claim 12 wherein the pressure control system comprises:

a collection tank fluidicly coupled to the fluid recovery outlet; and

a controllable vacuum regulator configured to regulate a pressure in the collection tank;

wherein the controller is configured to control the controllable vacuum regulator to adjust the flow rate of the fluid drawn from the space through the fluid recovery outlet to the collection tank by controlling the pressure in the collection tank.

15. The apparatus of claim 9 wherein the inner part is spaced from the outer part by an intermediate spacing.

16. The apparatus of claim 9 wherein the inner part includes an inner cavity forming a part of the spacing between the lens and the substrate, and wherein the inner part includes apertures disposed above the inner cavity for at least one of introducing fluid into and drawing fluid from the inner cavity.

17. The apparatus of claim 16 wherein the inner part includes apertures disposed on opposite sides of the lens opening for introducing fluid into the inner cavity.

18. The apparatus of claim 9 wherein the inner part includes a pair of buffer slots disposed on opposite sides of the lens opening.

19. The apparatus of claim 18 wherein the inner part includes purge holes and wherein each of the pair of buffer slots is fluidicly coupled to at least one of the purge holes.

20. The apparatus of claim 9 wherein the porous member is selected from the group consisting of a mesh, a porous material, and a member having etched holes therein.

21. An apparatus, comprising:

an optical projection system having a last optical element, the optical projection system configured to project an image onto a workpiece;

a stage configured to support the workpiece adjacent the optical projection system when the image is being projected onto the workpiece;

a gap between the last optical element and the workpiece, the gap being configured to be filled with an immersion fluid;

a porous material, positioned adjacent the gap, the porous material configured to recover fluid exiting the gap; and

a control system configured to maintain a pressure on the porous material, the pressure being at or below the bubble point of the porous material.

22. The apparatus of claim 21 wherein the control system comprises:

an overflow container fluidicly coupled with the porous member; and

a vacuum regulator configured to regulate a pressure in the overflow container.

23. The apparatus of claim 22 further comprising a collection tank fluidicly coupled to and disposed below the overflow container.

24. The apparatus of claim 21 wherein the control system comprises:

a fluid level buffer fluidicly coupled with the porous material;

a sensor configured to sense a pressure or a fluid level at the fluid level buffer; and

a controller configured to adjust a flow rate of the fluid drawn from the gap through a fluid recovery outlet, based on a sensor signal from the sensor, to maintain a pressure at the surface of the porous material below a bubble point of the porous material during drawing of the fluid from the space via the porous material.

25. The apparatus of claim 24 wherein the control system comprises a valve disposed downstream of the fluid recovery outlet, and wherein the controller is

configured to control the valve to adjust the flow rate of the fluid drawn from the space through the fluid recovery outlet.

26. The apparatus of claim 24 wherein the control system comprises:

a collection tank fluidicly coupled to the fluid recovery outlet; and

a controllable vacuum regulator configured to regulate a pressure in the collection tank;

wherein the controller is configured to control the controllable vacuum regulator to adjust the flow rate of the fluid drawn from the space through the fluid recovery outlet to the collection tank by controlling the pressure in the collection tank.

27. An apparatus comprising:

an optical projection system having a last optical element, the optical projection system configured to project an image onto a workpiece;

a stage configured to support the workpiece adjacent the optical projection system when the image is being projected onto the workpiece; and

a nozzle configured to provide immersion fluid in the gap between the last optical element and the workpiece,

wherein the nozzle includes an inner cavity to retain the immersion fluid in the gap, and an outer cavity to recover immersion fluid that exits the inner cavity.

28. The apparatus of claim 27 wherein the nozzle further comprises a groove between the inner cavity and the outer cavity.

29. The apparatus of claim 27 wherein the nozzle further comprises a porous member disposed in the outer cavity.

30. The apparatus of claim 29 wherein the porous member is selected from the group consisting of a mesh, a porous material, and a member having etched holes therein.

31. The apparatus of claim 27 wherein the inner cavity forms a part of a spacing between the last optical element and the workpiece, and wherein the nozzle includes apertures disposed above the inner cavity for at least one of introducing fluid into and drawing fluid from the inner cavity.

32. The apparatus of claim 31 wherein the apertures are disposed on opposite sides of the last optical element.

33. The apparatus of claim 27 wherein the nozzle further comprises a pair of buffer slots disposed on opposite sides of the last optical element along a direction of movement of the stage with respect to the optical projection system.

34. The apparatus of claim 33 wherein the nozzle further comprises purge holes, and wherein each of the pair of buffer slots is fluidicly coupled to at least one of the purge holes.

35. The apparatus of claim 12 further comprising a fluid supply or a fluid recovery fluidicly coupled with the fluid level buffer.

36. The apparatus of claim 24 further comprising a fluid supply or a fluid recovery fluidicly coupled with the fluid level buffer.

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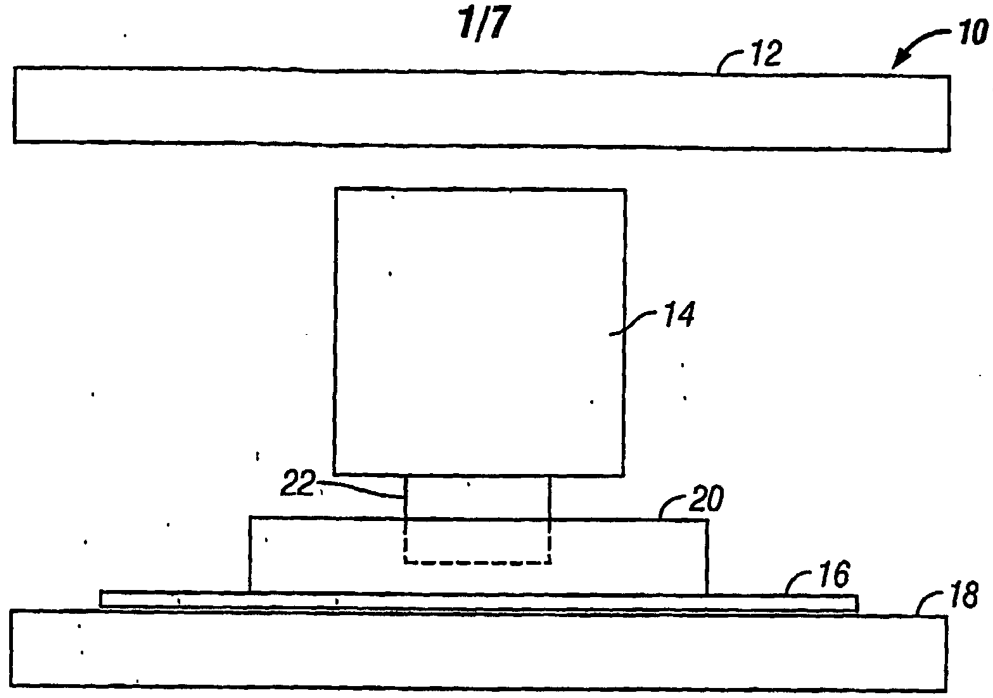


FIG. 1

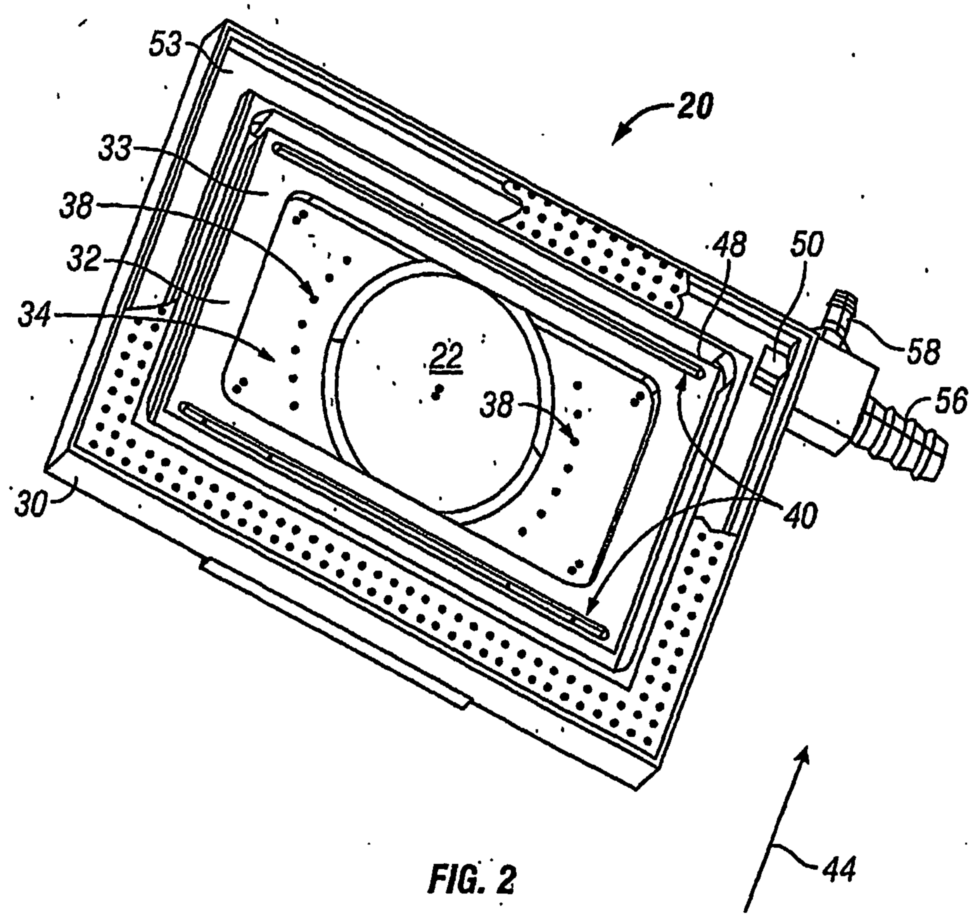


FIG. 2

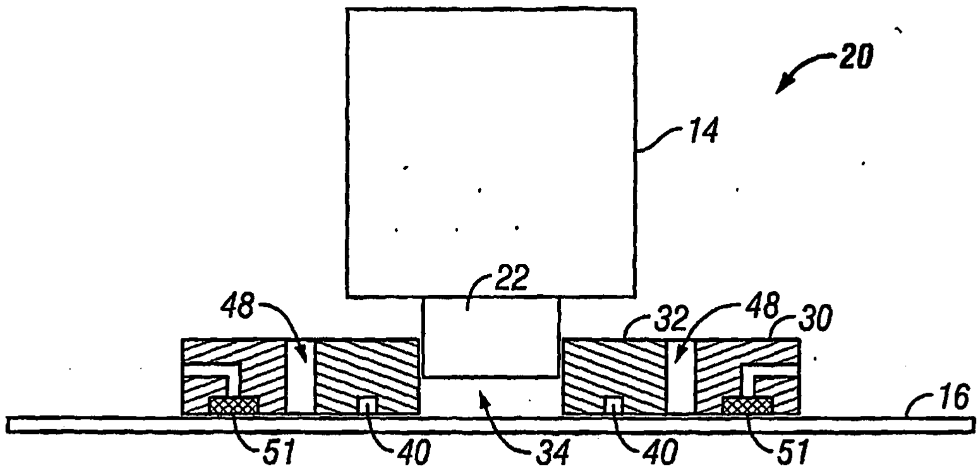


FIG. 3

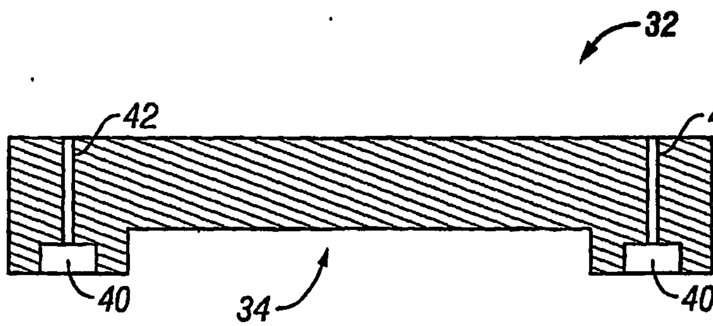


FIG. 4

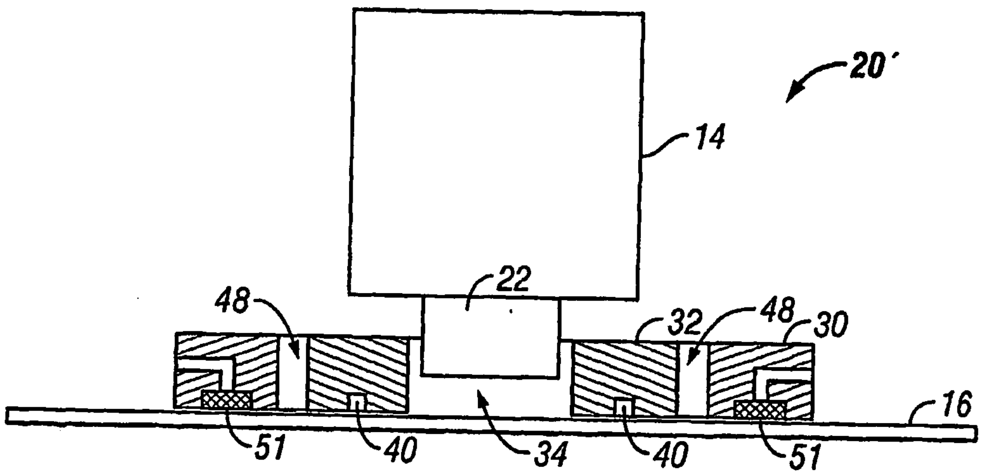


FIG. 5

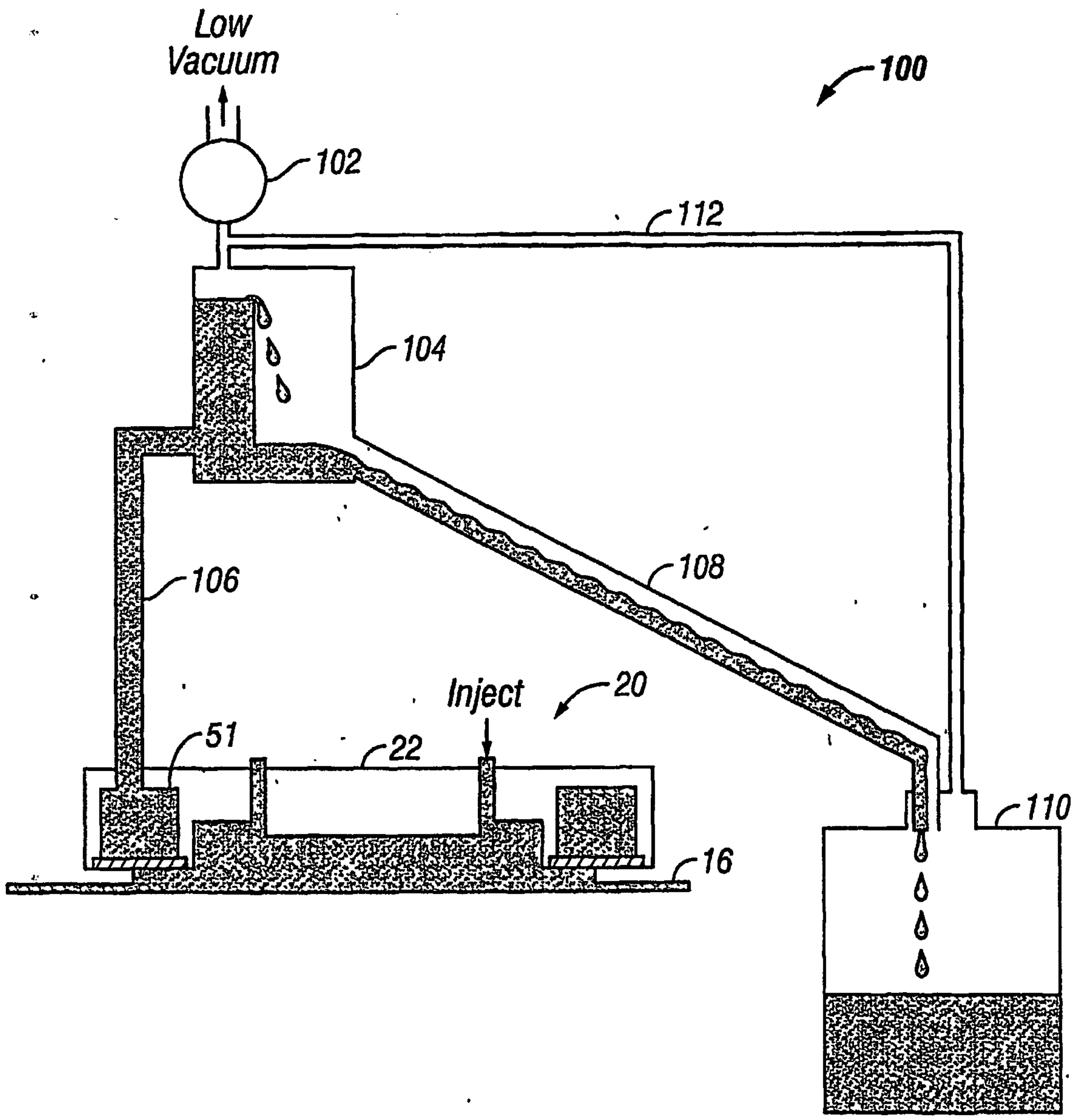
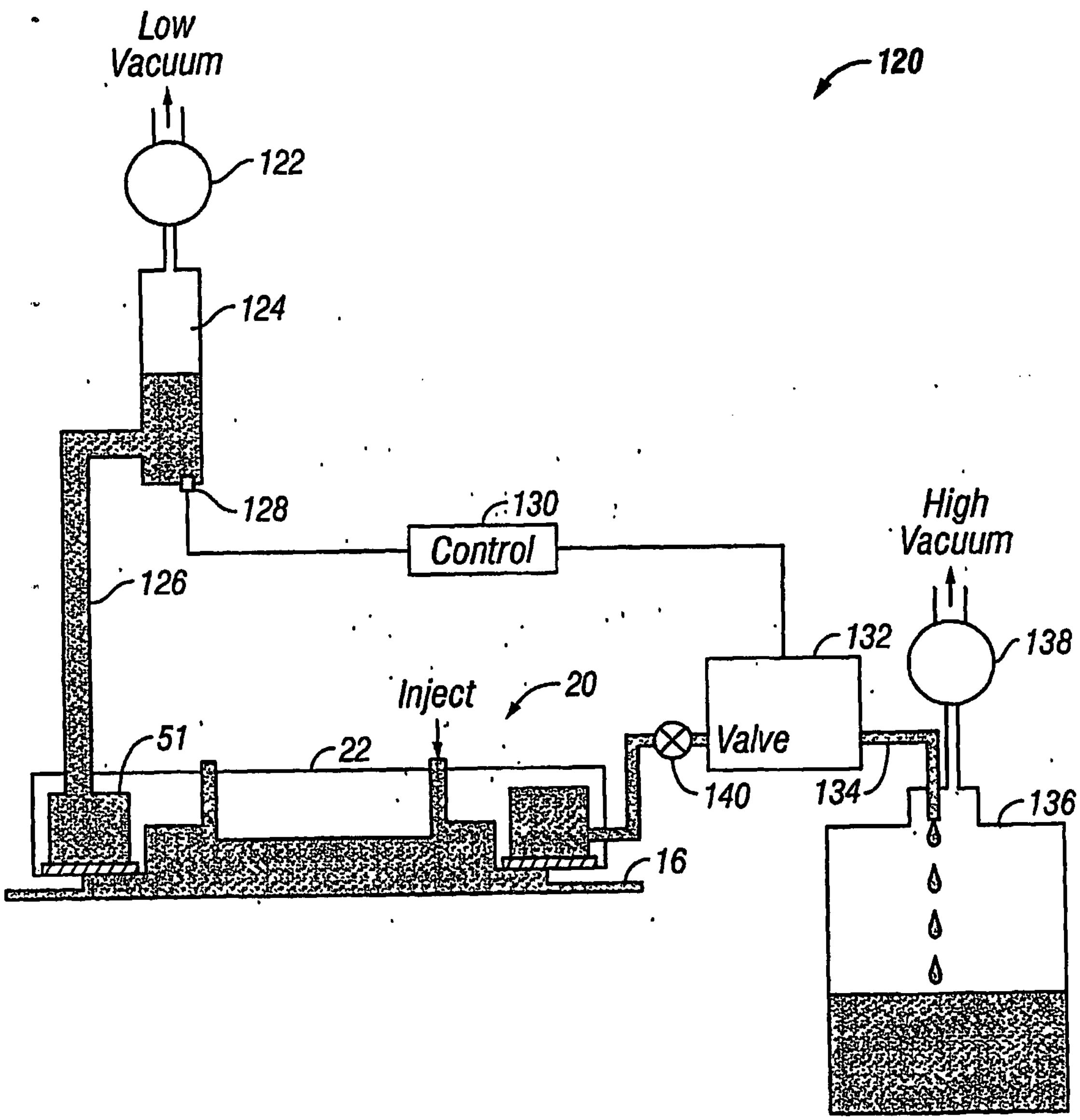


FIG. 6



Low Vacuum
120
122
124
128
130
Control
High Vacuum
126
132
138
Inject
20
51
22
Valve
140
134
136
16

FIG. 7

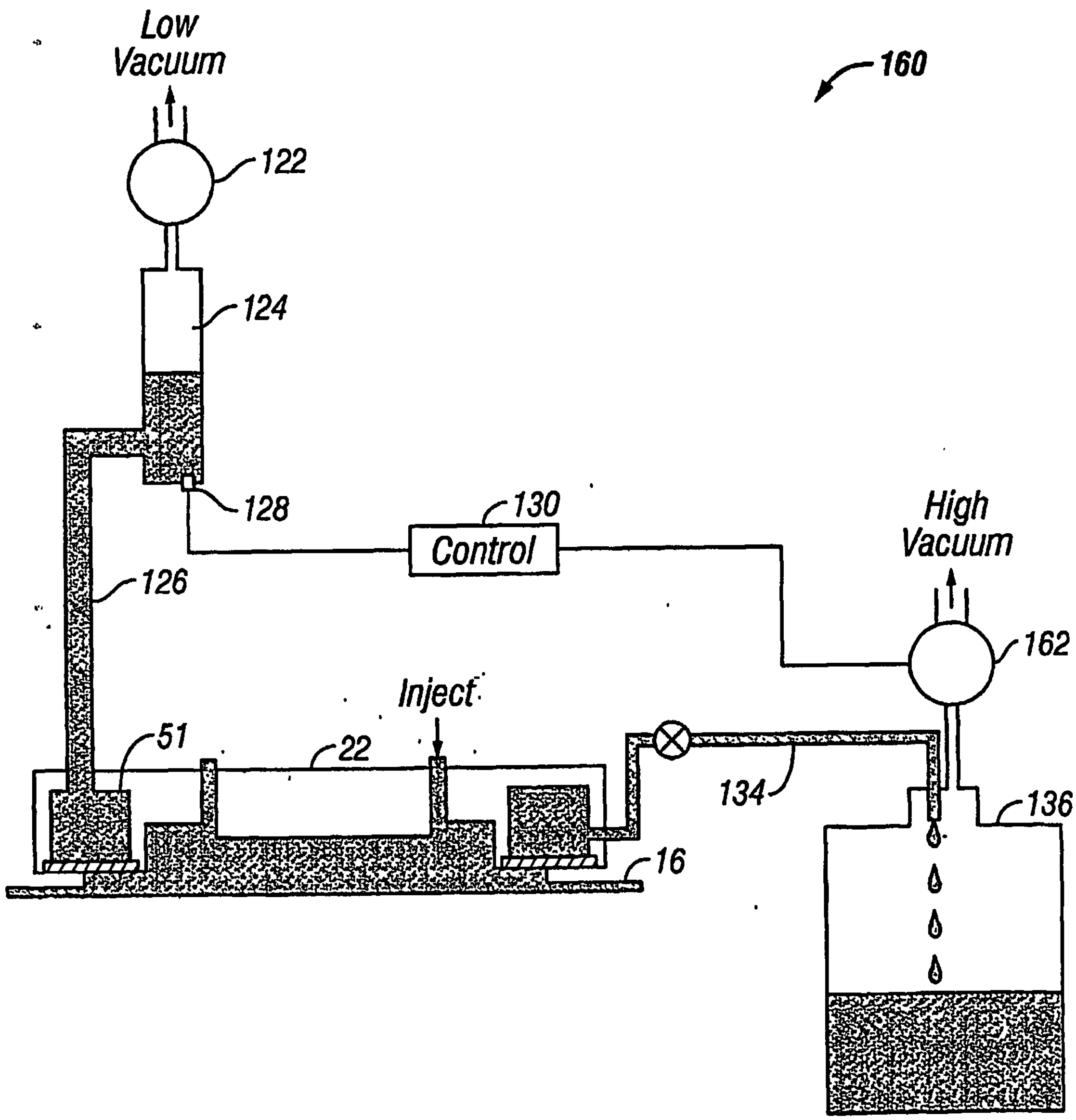

Low
Vacuum
160
122
124
128
130
Control
High
Vacuum
126
162
Inject
51
22
134
136
16

FIG. 8

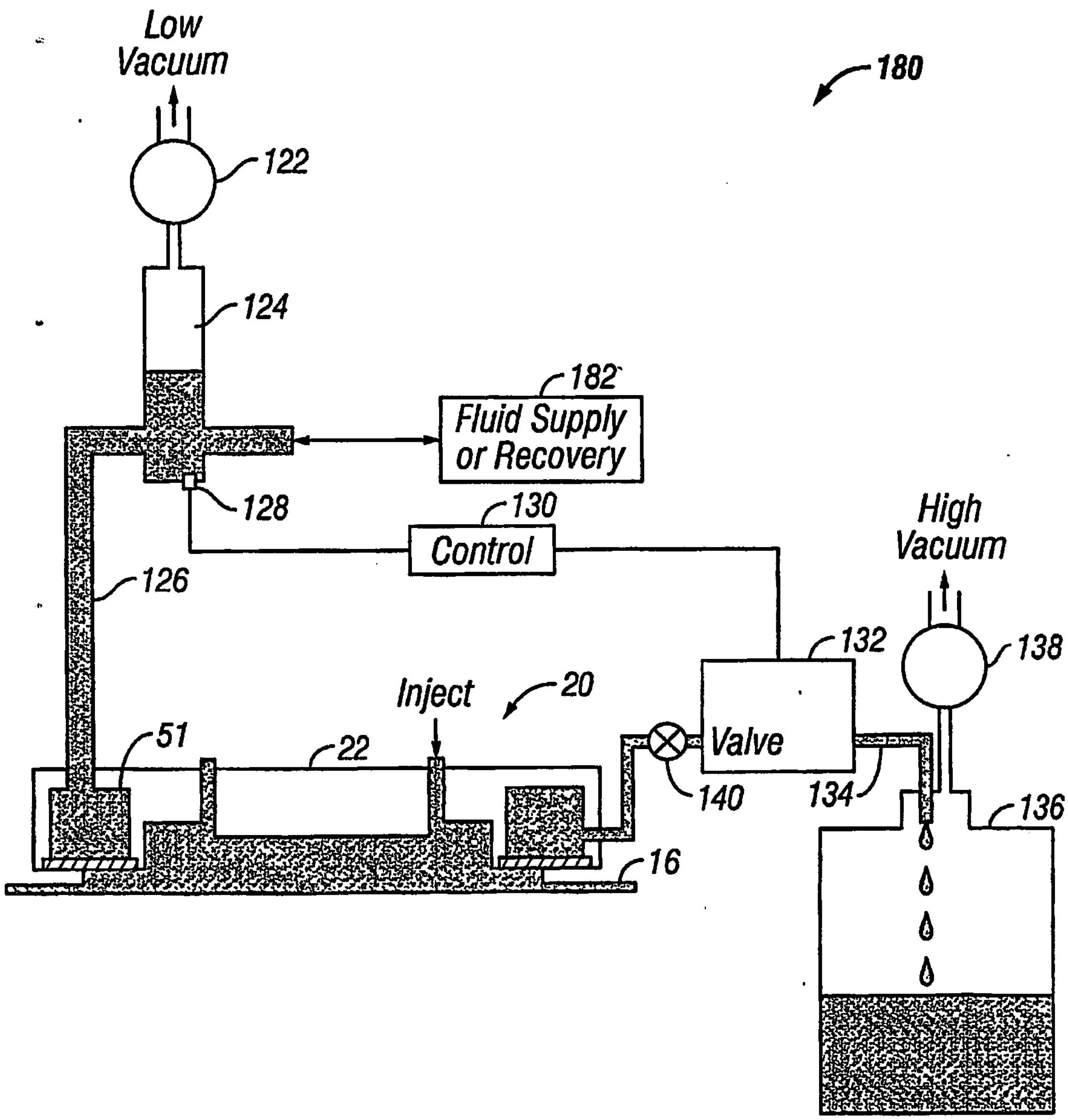

Low
Vacuum
180
122
124
182
Fluid Supply
or Recovery
128
130
Control
High
Vacuum
126
132
138
Inject
20
51
22
Valve
140
134
136
16

FIG. 9